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Subtherapeutic Antibiotics and Productivity in U.S. Hog Production

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Antimicrobial drugs are fed to hogs at subtherapeutic levels to prevent disease and promote growth. However, there is concern that the presence of antimicrobial drugs in hog feed is a factor promoting the development of antimicrobial drug-resistant bacteria. This study uses a treatment-effects sample-selection model to examine the impact that feeding antibiotics has on the productivity of U.S. hog operations. No relationship was found between productivity and antibiotics fed during finishing, but productivity was significantly improved when antibiotics were fed to nursery pigs. Restrictions on feeding antimicrobial drugs during the nursery phase would likely impose significant economic costs on U.S. hog producers.

Subtherapeutic levels of antimicrobial drugs have been fed to hogs to prevent disease, promote growth, and improve overall animal health since the 1950s. A 1999 study by a National Academy of Sciences committee concluded that most drugs and drug residues found in animal-derived foods posed a relatively low public risk so long as the drugs were used responsibly and according to label instructions (National Research Council). A more recent study lends support for the low public risk associated with feeding antimicrobial drugs (Phillips et al.). However, concerns persist that the use of antimicrobial drugs in hog feed could promote development of antimicrobial drug-resistant bacteria (Goldberg and Wallinga). As many of the drugs used to treat hogs are the same or similar to drugs used in human health care, the worry is that drug resistant organisms may pass from swine to humans through the handling of swine or through the consumption of pork products.

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Concerns about antimicrobial drug-resistant bacteria prompted several European countries to ban the use of growth-promoting antimicrobial drugs in hog production as a precautionary measure. Sweden, Norway, Finland, and Denmark were among the first to impose bans (Hayes et al.). A European Union-wide ban on the use of antibiotics as growth promoters went into effect in 2006. In the United States, subtherapeutic use of antimicrobial drugs for hog production has faced increasing scrutiny by public interest groups and the federal Food and Drug Administration. Some major U.S. food companies have announced that they will stop supplying consumers with livestock products that were raised using antibiotics for growth promotion (Hayes and Jensen; USA Today). Legislation has also been introduced to ban selected antibiotics (Mathews).

Despite these concerns, it is generally accepted that the productivity of major inputs used in swine production, feed, labor, and capital, can be improved on some operations by feeding antibiotics. Possible modes of action are commonly grouped into three categories: (1) nutritional effects, (2) disease prevention effects, and (3) metabolic effects (Cromwell). Feed efficiency can be increased by feeding low levels of antibiotics to improve nutrient absorption and depress the growth of organisms competing for nutrients. By suppressing disease-causing organisms in the animals' environment, antibiotics may reduce the incidence of diseases that hinder performance and thus raise the efficiency of labor and capital use. This suggests that the greatest productivity response to antibiotics may be on those operations with less than ideal environmental and management conditions—such as those with older buildings, less clean buildings, buildings with mixed-age swine, or those with hogs of inferior genetic potential.

To measure the effect of antibiotics on farm productivity, differences between farmers who choose to use antibiotics and those that do not should be considered. For example, antibiotic users may be younger, have larger operations, be more risk averse, or as discussed above, may be producing hogs under poorer environmental and management conditions. A problem is that some of these factors are unobservable and may be correlated with both antibiotic use and productivity. In this case, simply regressing productivity on exogenous factors and an indicator of antibiotic use would result in biased parameters. For example, if poor environmental and management conditions of the hog operation are positively correlated with antibiotic use, but are negatively correlated with productivity, then a simple regression would understate the impact of antibiotic use on productivity. This is a problem of self-selection because antibiotic users would have lower productivity due to poorer environmental and management conditions whether or not they chose to use antibiotics.

This study uses a sample selection model to account for the fact that some determinants of both whether a farmer uses antibiotics and farm productivity are unobservable. Two equations are estimated simultaneously in the sample selection model: (1) a probit equation explaining the decision of whether or not to use antibiotics, and (2) an equation explaining productivity, which includes an indicator of antibiotic use among the explanatory variables. The empirical model corrects for possible sample selection bias by accounting for the joint distribution of the disturbances. Data from a sample of U.S. hog producers surveyed as part of the 2004 Agricultural Resource Management Survey are used in the model (U.S. Dept. of Agriculture, Economic Research Service). Empirical results identify determinants of hog farmers' decisions to use antibiotics and also identify factors that influence productivity. Results also provide an indication of the potential impacts that restrictions on feeding antimicrobial drugs to hogs would have on industry productivity in the United States—important information for hog producers and policymakers evaluating the implications of legislation that call for such restrictions.

Impacts of Feeding Antibiotics

Data from the European experience with a ban on subtherapeutic antibiotics have been used to present possible implications of such a ban for U.S. hog producers. Hayes et al. extrapolated from the European experience with a ban using technical data obtained from Sweden to draw implications for U.S. hog producers. Their analysis assumed that an antibiotic feeding ban would increase average weaning age by one week, and days to reach 50 pounds by 5, while decreasing feed efficiency by 1.5%. While recognizing some basic differences between production practices in Sweden and the United States, the authors predicted that U.S. production costs per head would increase between \$5 and \$6, and profits would decline \$0.79 per head by banning subtherapeutic antibiotics. The Swedish experience also suggested that the impact of the ban would be greatest on farms with questionable hygiene practices, such as those that weaned pigs into cold, old, continuous flow buildings.

In a follow-up study, Hayes and Jensen explored the consequences of Denmark's ban on feed-grade antibiotics in order to present lessons for the U.S. hog sector. The authors found that Danish hog producers encountered few costs when antibiotics were withdrawn at the finishing stage, but severe health problems and large costs were incurred with a ban on antibiotics at the weaning stage.[1] Other important findings were the wide variation in the effects incurred among producers, with producers using practices that reduce the pressure of infectious diseases, such as all-in/all-out processes, being least affected by the ban. The primary lessons for U.S. producers were that a ban on antibiotics at the finishing stage might lead to a slight reduction in feed efficiency and an increase in the weight variation of finished hogs, but would create few animal health problems. However, a ban at the weaning stage could create serious animal health problems and lead to a significant increase in mortality. Their estimates suggested a first-year cost of \$4.50 per head due to the ban of subtherapeutic antibiotics.

Miller et al. (December 2003) measured the productivity and economic impact of antibiotics for growth promotion in the grower/finisher phase of hog production using data collected from U.S. farms in the 1990 and 1995 National Animal Health Monitoring System (NAHMS). The authors conducted regressions using NAHMS data that related productivity measures—average daily gain, feed efficiency, and mortality rate—to antibiotic use and other potentially relevant factors of production. Antibiotics fed for growth promotion in the grower/finisher phase were found to improve average daily gain by 1.1%, feed conversion by about 0.5%, and were associated with reduced hog mortality. In total, these productivity improvements translated to an estimated profitability gain of roughly \$0.59 per head. The authors were careful to note the data and analytical limitations of the study, such as the lack of information on antibiotic use in the gestation and farrowing phases, that the role of antibiotics for disease prevention was not considered, and that data on the influence of management (animal husbandry) were limited.

Miller et al. (2005) extended their original study by considering pigs stunted as an additional productivity measure, moving to a system of equations estimation, and employing 2000 NAHMS data that allowed them to more thoroughly characterize management in their model. Results confirmed earlier findings that antibiotics for growth promotion in the grower/finisher stage had a statistically significant impact on average daily gain, but antibiotic use was not statistically significant in estimated relationships with animal feed conversion or pig mortality. Using these findings, a complete ban on subtherapeutic antibiotics was estimated to cost producers approximately \$1.37 per head. The study also suggested that it may be possible for producers to somewhat offset the productivity impacts of a ban by using improved management techniques, such as receiving pigs from on-site sources and tailoring diets more closely to pig needs.

In other work using the 2000 NAHMS data, Liu, Miller, and McNamara examined whether antibiotics reduced production risk among U.S. hog producers. Variability of live weight for growing/finishing pigs was defined as the measure of production risk and regressed against variables describing the use of antibiotics for growth promotion. Results suggested that risk is reduced and profits are increased from feeding antibiotics to growing/finishing pigs. The combined impacts of increased average daily gain and decreased variability in pig weights were estimated to increase producer profits by \$2.99 per head.

This past research provides insight into the mechanisms by which antibiotics could impact hog farm productivity, which informs the empirical approach taken in this study. However, none of the prior studies have accounted for the potential effect of selection bias on the estimated impact. The empirical approach in this study contributes to the literature by tackling the issue of self-selection with regard to measuring the impact of antibiotic use on the productivity of U.S. hog operations. Further, this study addresses whether the impact of antibiotics on hog farm productivity differs depending on which stage of production the antibiotics are fed.

Empirical Approach

A treatment-effects sample-selection model is employed to measure the impact of subtherapeutic antibiotic (STA) use on input productivity (Greene). The model assumes a joint normal distribution between the errors of the selection equation (STA use or not) and the treatment equation (the measure of productivity). This approach accounts for the possible correlation of unobservable variables with both the decision to use STA and productivity, allowing for an unbiased estimate of the impact of STA on productivity.

Applying the treatment-effects model, the decision to use STA or not can be expressed with the latent variable A_i^* indicating the net benefit from using antibiotics compared to not using, so that:

$$(1) \qquad A_i^* = Z_i\gamma + u_i;\ \text{where } A_i = 1 \text{ if } A_i^* > 0,\ 0 \text{ otherwise}$$

where Z_i is a vector of operator, farm, and regional characteristics. If the latent variable is positive, then the variable indicating antibiotic use A_i equals one, and equals zero otherwise. A measure of the impact of STA use on productivity y_i can be expressed by

$$y_i = X_i\beta + A_i\delta + \varepsilon_i \tag{2}$$

where X_i is a vector of operator, farm, and regional characteristics.

Equation (2) cannot be estimated directly because the decision to use antibiotics may be determined by unobservable variables, such as environmental and management conditions, that may also affect performance. If this is the case, the error terms in equations (1) and (2) will be correlated, leading to a biased estimate of δ. This selection bias can be accounted for by assuming a joint normal error distribution with the following form:

$$\begin{bmatrix} u \\ \varepsilon \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & \sigma^2 \end{bmatrix}\right)$$

and by recognizing that the expected performance of antibiotic users is given by

$$E[y_i \mid A_i = 1] = X_i\beta + \delta + \rho\sigma\lambda_i \tag{3}$$

where λ_i is the inverse Mills ratio. To derive an unbiased estimate of δ, a two-stage approach can be used starting with a probit estimation of equation (1). In the second stage, estimates of γ are used to compute the inverse Mills ratio, which is included as an additional term in an ordinary-least-squares estimation of equation (2). This two-stage Heckman procedure is consistent, albeit not efficient. Efficient maximum likelihood parameter estimates can be obtained by maximizing:

$$\begin{aligned} L(\gamma, \beta, \sigma, \rho) = &\prod_{A_i=0} \int_{-\infty}^{0} \int_{-\infty}^{\infty} f\left(A_i^*, y_i; \gamma, \beta, \sigma, \rho\right) dy\, dA^* \\ &\cdot \prod_{A_i=1} \int_{0}^{\infty} \int_{-\infty}^{\infty} f\left(A_i^*, y_i; \gamma, \beta, \sigma, \rho\right) dy\, dA^* \end{aligned}$$

where $f(A_i^*, y_i; \gamma, \beta, \sigma, \rho)$ is the joint normal density function, which is a function of the parameters. In practice, the negative of the log of the likelihood function is minimized using the estimates from the Heckman procedure as starting values.

Data

Data used in this study come from the 2004 Agricultural Resource Management Survey (ARMS) of U.S. hog producers. The 2004 ARMS of hog producers includes data from 1,198 hog producers in nineteen states. Unlike the data used in previous research, the ARMS data include detailed farm financial information such as farm income, expenses, assets, and debt, and farm and operator characteristics. The 2004 ARMS also included detailed information about the production practices and costs of hog production.

Table 1. Frequency of antibiotic feeding in U.S. hog production, by producer type, 2004

	Antibiotics fed for:			
Producer type	**Growth Promotion**	**Disease Prevention**	**Disease Treatment**	**Subtherapeutic Use**
	Percentage of farms feeding			
Farrow-to-finish				
Breeding animals	13	43	20	44
Nursery pigs	38	62	25	64
Finishing hogs	43	38	22	51
Farrow-to-feeder pig				
Breeding animals	17	54	44	68
Nursery pigs	23	15	8	31
Feeder pig-to-finish				
Finishing hogs	44	60	58	67
Farrow-to-wean				
Breeding animals	5	40	37	40
Wean-to-feeder pig				
Nursery pigs	42	84	80	85

Notes: Subtherapeutic use is the feeding of antibiotics for either growth promotion or disease prevention. Producer types are defined in McBride and Key.
Source: 2004 Agricultural Resource Management Survey.

In the hog version of the ARMS, producers were asked whether they fed antibiotics to breeding animals, nursery pigs, and/or finishing hogs. For each of these animal classes, producers were asked whether the antibiotics were fed for growth promotion, disease prevention, and/or disease treatment. A breakdown of antibiotic use for each purpose by different types of hog producers is shown in table 1. Antibiotics were most often fed for disease prevention, especially to nursery pigs. Antibiotic feeding for growth promotion was most common for finishing hogs, reported by more than 40% of farrow-to-finish and feeder pig-to-finish operations, but was also common for nursery pigs on farrow-to-finish and on wean-to-feeder pig operations. Wean-to-feeder pig operations were most likely to feed antibiotics for disease treatment, done on 80% of operations. These operations have weaned pigs placed on the operation at a very young age and feeding antibiotics is a strategy for maintaining the health of these young pigs that are highly susceptible to disease. For the analysis in this study, users of STA were defined as operations that reported antibiotics fed for the purpose of either growth promotion or disease prevention.

The empirical analysis of STA use and impact in this study was confined to feeder pig-to-finish and farrow-to-finish operations because of the large sample size available for these producers. After deleting forty-two feeder pig-to-finish and five farrow-to-finish observations due to missing data on antibiotic use, 436 feeder pig-to-finish and 326 farrow-to-finish operations were available for the analysis. Less than 100 observations were available for each of the other producer types. The treatment variable in the feeder pig-to-finish model was STA fed to finishing hogs. In order to examine the impact of STA use at different stages of production, two models were estimated for farrow-to-finish producers. In one model the treatment variable was STA use for nursery pigs, while in the other STA use for finishing hogs was specified. STA use in both the nursery and finishing stages of farrow-to-finish production are examined because previous research suggests differential impacts from treating nursery pigs and finishing hogs.

Variables specified in the estimated selection and productivity equations for feeder pig-to-finish and farrow-to-finish operations are shown in tables 2 and 3.

Table 2. Tests of equality of means for subtherapeutic antibiotic users and nonusers among U.S. feeder pig-to-finish operations, 2004

	STA for Finishing		
Variable Description	Mean Users	Mean Nonusers	*t*-stat
Total factor productivity[a]	3.10	3.11	0.02
Age (years)	49.86	52.20	1.76
Education (years)	13.68	14.12	0.76
Primary occupation is off-farm[b]	0.17	0.18	0.13
Years in hog business	13.11	13.62	0.19
Planning horizon (years)	12.83	10.56	1.66
Size class 1: less than 500 hogs[b,c]	0.16	0.46	2.50
Size class 2: 500–1,999 hogs[b,c]	0.40	0.28	1.50
Size class 3: 2,000–4,999 hogs[b,c]	0.29	0.20	1.35
Size class 4: 5,000 or more hogs[b,c]	0.14	0.05	1.53
Specialization in hogs (proportion)[d]	0.68	0.47	2.56
Location in Midwest (IA, IL, IN, OH)[b]	0.52	0.38	1.57
Location in East (NC, VA, PA)[b]	0.12	0.07	1.26
Location in South (AR, GA, KY, MO)[b]	0.04	0.02	0.61
Location in North (MI, MN, WI, SD)[b]	0.23	0.22	0.09
Location in West (CO, KS, NE, OK)[b]	0.09	0.30	1.54
Hog production contract[b]	0.51	0.39	0.98
Hog buyer requires no antibiotic use[b]	0.08	0.29	1.92
Closed confinement finishing facilities[b]	0.84	0.49	3.79
Finishing facility age (years)	13.78	13.77	0.01
Purchase/placement weight (pounds)	41.19	44.79	0.69
All-in/all-out finishing management[b]	0.80	0.76	0.55
Number of rations fed	4.48	3.49	2.20
Split-sexed feeding[b]	0.38	0.25	1.34
Finishing disease treatment[b]	0.72	0.29	4.83
Number of observations	326	110	

Notes: Statistical significance in test of equality of means is indicated by *t*-statistics greater than 1.96 and 1.65 at the 5% and 10% levels, respectively.
Source: 2004 Agricultural Resource Management Survey.
[a]cwt of hog production per dollar of total factor cost (X 10^{-2}).
[b]Binary variable equal to 1 if the characteristic or practice applies, 0 otherwise.
[c]Size is measured by the maximum number of hogs in inventory any time during 2004.
[d]Proportion of the total value of farm production that was generated by hog production.

Table 3. Tests of equality of means for subtherapeutic antibiotic users and nonusers among U.S. farrow-to-finish operations, 2004

	STA for Nursery			STA for Finishing		
Variable Description	Mean Users	Mean Nonusers	*t*-stat	Mean Users	Mean Nonusers	*t*-stat
Total factor productivity[a]	1.35	1.05	1.43	1.36	1.11	1.15
Age (years)	49.11	55.61	1.52	50.94	52.00	0.24
Education (years)	13.21	12.68	1.37	13.24	12.78	1.15
Primary occupation is off-farm[b]	0.21	0.19	0.13	0.20	0.20	0.00
Years in hog business	20.64	17.59	0.58	20.98	18.04	0.56
Planning horizon (years)	10.62	10.28	0.24	10.63	10.36	0.19
Size class 1: less than 500 hogs[b,c]	0.53	0.74	1.13	0.55	0.67	0.79
Size class 2: 500-1,999 hogs[b,c]	0.35	0.23	0.63	0.32	0.29	0.22
Size class 3: 2,000-4,999 hogs[b,c]	0.08	0.01	3.10	0.08	0.03	2.10
Size class 4: 5,000 or more hogs[b,c]	0.04	0.01	1.61	0.05	0.01	2.02
Specialization in hogs (proportion)[d]	0.48	0.46	0.19	0.52	0.42	1.06
Location in Midwest (IA, IL, IN, OH)[b]	0.37	0.15	2.06	0.34	0.25	0.91
Location in East (NC, VA, PA)[b]	0.03	0.04	0.51	0.01	0.10	1.78
Location in South (AR, GA, KY, MO)[b]	0.14	0.21	0.76	0.11	0.22	1.54
Location in North (MI, MN, WI, SD)[b]	0.31	0.14	1.38	0.32	0.18	0.95
Location in West (CO, KS, NE, OK)[b]	0.13	0.42	1.69	0.21	0.25	0.27
Hog buyer requires no antibiotic use[b]	0.09	0.14	0.54	0.04	0.19	2.03
Closed confinement nursery facilities[b]	0.78	0.25	4.04	0.72	0.45	1.84
Nursery facility age (years)	15.88	8.46	2.11	15.72	10.58	1.41
All-in/all-out nursery management[b]	0.60	0.17	3.60	0.59	0.29	2.25
Closed confinement finishing facilities[b]	0.49	0.24	1.51	0.48	0.30	1.07
Finishing facility age (years)	19.03	18.94	0.02	19.23	18.75	0.15
All-in/all-out finishing management[b]	0.23	0.16	1.05	0.22	0.18	0.59
Weaning age (days)	29.82	40.25	4.82	30.43	36.87	2.34
Terminal crossbreeding[b]	0.24	0.14	1.37	0.25	0.16	1.08
Rotational crossbreeding[b]	0.63	0.53	0.59	0.63	0.56	0.40
Artificial insemination[b]	0.26	0.08	2.36	0.23	0.16	0.72
Number of rations fed	4.31	2.71	4.99	4.26	3.19	2.25
Split-sexed feeding[b]	0.24	0.05	1.46	0.28	0.06	1.37
Nursery disease treatment[b]	0.36	0.06	3.98	0.33	0.17	1.75
Finishing disease treatment[b]	0.28	0.11	2.76	0.33	0.09	2.75
Number of observations	228	98		175	151	

Notes: Statistical significance in test of equality of means is indicated by *t*-statistics greater than 1.96 and 1.65 at the 5% and 10% levels, respectively.
Source: 2004 Agricultural Resource Management Survey.
[a]cwt of hog production per dollar of total factor cost (X 10^{-2}).
[b]Binary variable equal to 1 if the characteristic or practice applies, 0 otherwise.
[c]Size is measured by the maximum number of hogs in inventory any time during 2004.
[d]Proportion of the total value of farm production that was generated by hog production.

Total factor productivity is measured for each operation as the hundredweight of animal gain per dollar of total costs. Total costs are a measure of the total economic costs of hog production, excluding costs for nursery and feeder pigs purchased or placed on the operation.[2] Exogenous variables specified in the model include farm operator and farm characteristics, and a set of hog production practices. Operator characteristics, such as operator age, education, primary occupation, and planning horizon are included to account for differences in operator knowledge, goals, and time devoted to hog production. Farm characteristics account for differences in the structure of hog operations (e.g., size and specialization) and location. Climatic differences related to farm location may be important to the decision to use STA because of differences in animal disease susceptibility. Other farm characteristics that may affect the STA use decision are the use of production contracts, through which contractors are supplying feed that may include STA, and whether the hog buyer (or contractor) requires that the hogs not be fed antibiotics at any time.

Hog production practices expected to be associated with the selection of STA and productivity include type and age of facilities, the weaning age of nursery pigs, and the purchase/placement weight of pigs to be finished. Type of facility indicates the degree to which hogs are confined and thus is an indicator of the potential for spreading disease. Facility age reflects the level of technology and may influence the quality of environment to which hogs are exposed. Early weaning and placing younger pigs in finishing facilities can create conditions where pigs are more susceptible to disease because natural immunities have yet to form and thus antibiotics may be used to maintain herd health. A number of other variables are specified in the productivity equation, including all in/all out production, crossbreeding program, artificial insemination, the number of rations fed, and split-sexed feeding. Accounting for these variables is necessary to isolate the association between productivity and STA use. Therapeutic antibiotic use (for disease treatment) is also added to reflect the impact that the presence of disease problems had on productivity.[3]

Tables 2 and 3 also include a comparison of variable means for STA users and nonusers. The mean comparisons indicate little statistical difference in operator characteristics (e.g., age, education, primary occupation) between users and nonusers of STA. Also interesting is that the difference in the use of production contracts between the groups was not statistically significant. Some variables for size of the hog operation were statistically different as was the variable for farm specialization in hog production on hog finishing operations, suggesting that STA use is more common on larger, specialized hog operations. Other differences among users and nonusers on feeder pig-to-finish operations (table 2) were that STA use was more common on operations with closed confinement facilities, those adjusting rations more often to match animal needs, and those using antibiotics for disease treatment. However, mean factor productivity was statistically identical for the users and nonusers of STA on hog finishing operations.

On farrow-to-finish operations several characteristics of the hog operation and several hog production practices were statistically different between users and nonusers of STA for nursery pigs (table 3). Nursery facilities were more often closed confinement, had more years of age, and more often were managed as all-in/all-out on operations using STA. STA users during the nursery phase also weaned pigs earlier, more often used antibiotics for disease treatment, and more often used such performance enhancing practices as artificial insemination and adjusting hog rations. Fewer characteristics were significantly different among STA users and nonusers on operations feeding antibiotics during finishing, but differences in weaning age, number of rations fed, and feeding antibiotics for disease treatment were significant. Mean factor productivity was higher for STA users than nonusers during both the nursery and finishing phases on farrow-to-finish operations, but these differences were not statistically significant.

Results

Estimates for the STA selection and factor productivity equations for feeder pig-to-finish operations are shown in table 4. None of the operator characteristics were statistically significant in the estimated selection equation and few farm characteristics were significant. Greater farm specialization in hog production increased the likelihood of STA use on the finishing operations, while location in the western states, compared to the Midwest (the control group) decreased the likelihood. Of particular interest is the lack of statistical significance in the coefficients of the farm size and hog contracting variables. STA feeding is a relatively simple technology to employ and does not require a long-term investment in either financial or human capital. Therefore, it is not surprising that a scale bias was not found with STA selection. Also interesting is that contract operations fed STA neither more nor less often than other operations.

As one would expect, feeder pig-to-finish operations selling hogs to buyers or those that had contractors that specifically required hogs not to be fed antibiotics at any time were less likely to feed STA. Also, hog production practices including type and age of finishing facilities were statistically significant in the selection model. STA selection was more likely in closed confinement facilities that more closely crowd animals increasing the potential for disease transmission. STA use was also associated with older finishing facilities where animal care may not be at the same level as in more modern facilities and where STA use may be a practice used to maintain animal health.

Operator and farm characteristics were much more important for explaining variation in total factor productivity than for the STA selection decision on feeder pig-to-finish operations (table 4). Operator age and a primary occupation off-farm were negatively associated with factor productivity. Some older operators may be semiretired and may devote less time to the hog operation, or perhaps are more often using aged equipment that they do not plan to replace before retirement. Operators working primarily off-farm may have less time and fewer incentives to devote time to the hog operation. Size of operation was positively and strongly associated with productivity. In addition, the value of the coefficients increased with successive size categories indicating a positive relationship between scale and factor productivity.

Finishing hogs under a contract arrangement was positively associated with factor productivity at a high statistical significance. This finding is consistent with that found in prior work using ARMS survey data from 1998 (Key and McBride). The relationship may reflect the specialized knowledge and resources that contractors and growers each contribute to the production arrangement. Also of interest is that although contracting is most common in eastern states, location in those states was associated with lower productivity than location in the Midwest. It appears that once the impact of contracting is accounted for, the advantages of hog finishing in the Midwest (e.g., lower cost feed) improve productivity relative to location in eastern states.

Among hog production practices used on feeder pig-to-finish operations, the number of rations fed to finishing hogs was highly significant and had a positive impact on total factor productivity. This means that productivity was higher on operations that more closely matched feed rations with hog nutrient requirements at different weights, a result consistent with previous work (Miller et al. 2005).

Table 4. Selection model maximum likelihood estimates: Total factor productivity on U.S. feeder pig-to-finish operations, 2004

	Finishing Hogs	
Variable Description	**Coefficient**	**Standard Error**
Selection equation		
Constant	0.070	0.921
Age (years)	−0.005	0.009
Education (years)	−0.041	0.050
Primary occupation is off-farm	0.093	0.302
Years in hog business	0.002	0.011
Planning horizon (years)	0.011	0.014
Size class 2: 500–1,999 hogs	0.157	0.295
Size class 3: 2,000–4,999 hogs	0.148	0.354
Size class 4: 5,000 or more hogs	0.422	0.479
Specialization in hogs (proportion)	0.791**	0.400
Location in East (NC, VA, PA)	−0.136	0.251
Location in South (AR, GA, KY, MO)	0.325	0.336
Location in North (MI, MN, WI, SD)	0.019	0.264
Location in West (CO, KS, NE, OK)	−0.591**	0.282
Hog production contract	−0.249	0.263
Hog buyer requires no antibiotic use	−0.907**	0.335
Closed confinement finishing facilities	0.702**	0.249
Finishing facility age (years)	0.027**	0.013
Pig purchase/placement weight (pounds)	−0.002	0.004
All-in/all-out finishing management	−0.008	0.249
Factor productivity equation		
Constant	4.032**	0.910
Age (years)	−0.016*	0.009
Education (years)	−0.073	0.044
Primary occupation is off-farm	−0.670**	0.304
Years in hog business	0.020	0.014
Planning horizon (years)	−0.009	0.013
Size class 2: 500–1,999 hogs	0.475*	0.254
Size class 3: 2,000–4,999 hogs	1.255**	0.322
Size class 4: 5,000 or more hogs	1.263**	0.415
Specialization in hogs (proportion)	0.305	0.440
Location in East (NC, VA, PA)	−0.896**	0.302
Location in South (AR, GA, KY, MO)	0.285	0.250
Location in North (MI, MN, WI, SD)	0.072	0.367
Location in West (CO, KS, NE, OK)	−0.444	0.363

(*Continued*)

Table 4. Continued

	Finishing Hogs	
Variable Description	Coefficient	Standard Error
Hog production contract	0.984**	0.235
Closed confinement finishing facilities	0.080	0.305
Finishing facility age (years)	−0.026*	0.015
All-in/all-out finishing management	0.387	0.253
Finishing disease treatment w/antibiotics	−0.130	0.219
Number of rations fed	0.147**	0.047
Split-sexed feeding	−0.112	0.274
STA fed to finishing hogs	−1.183*	0.642
Sigma	1.468**	0.139
Rho	0.258	0.161
Log likelihood	−35,247	
Number of observations	436	

Notes: Dependent variable in the selection equation is the whether subtherapeutic antibiotics were fed to finishing hogs (0,1). Dependent variable in the factor productivity equation is cwt of hog production per dollar of total factor cost (X 10^{-2}). * and ** denote statistical significance at the 10% and 5% levels, respectively.

Facility age was negatively associated with productivity, but at a low level of significance. A surprising result was that the use of STA for finishing hogs was statistically significant and negatively associated with productivity, albeit at only the 10% level of significance. This result could be caused by defining STA use as that for either growth promotion or disease prevention. Miller et al. (July 2003) reported improved productivity from antibiotics fed to finishing hogs for growth promotion, but lower productivity from those fed for disease prevention.

Estimates for the STA selection and factor productivity equations for the farrow-to-finish operations are shown in table 5. Estimates are shown for both the selection of STA and the factor productivities in the nursery phase and in the finishing phase. Several farm operator characteristics were statistically significant with respect to STA selection for nursery pigs. Operator age and planning horizon were negatively related to STA selection, indicating that older operators and those approaching retirement were less likely to use STA. Operator education and experience, measured by years in the hog business, were positively associated with STA selection, which may reflect a higher level of management provided by more educated and experienced farm operators. All of these farm operator relationships are consistent with expectations about the adoption of farm technologies.

STA selection for nursery pigs was less likely in the eastern and western states compared to the Midwest. Differences in climatic conditions, such as warmer weather in eastern and some western states, may have influenced this relationship. Also, STA selection was more likely in closed confinement facilities perhaps because STA may reduce the potential for disease transmission among young pigs in these crowded facilities. Size of operation, as in the feeder pig-to-finish model, was not associated with the selection of STA. Also, the variable for buyer requirements for antibiotic-free hogs was not significant in the STA selection equation for nursery pigs. Hog buyers may not be as concerned about feeding STA to nursery pigs because they are several months from slaughter.

Parameter estimates for STA selection for finishing hogs on farrow-to-finish operations were much different than for nursery pigs and more similar to those on feeder pig-to-finish operations. No operator characteristics and few farm

Table 5. Selection model maximum likelihood estimates: Total factor productivity on U.S. farrow-to-finish operations, 2004

	Nursery Pigs		Finishing Hogs	
Variable Description	Coefficient	Standard Error	Coefficient	Standard Error
Selection equation				
Constant	0.714	0.986	−1.018	1.207
Age (years)	−0.031**	0.011	−0.006	0.014
Education (years)	0.110*	0.066	0.080	0.059
Primary occupation is off-farm	−0.237	0.320	−0.106	0.396
Years in hog business	0.017**	0.008	0.007	0.011
Planning horizon (years)	−0.410**	0.015	−0.012	0.015
Size class 2: 500–1,999 hogs	0.358	0.272	0.001	0.305
Size class 3: 2,000–4,999 hogs	0.889	0.742	0.378	0.383
Size class 4: 5,000 or more hogs	0.315	0.495	0.851*	0.503
Specialization in hogs (proportion)	−0.010	0.357	0.751	0.472
Location in East (NC, VA, PA)	−1.102*	0.580	−1.617**	0.474
Location in South (AR, GA, KY, MO)	−0.463	0.306	−0.439	0.274
Location in North (MI, MN, WI, SD)	−0.518	0.316	0.379	0.374
Location in West (CO, KS, NE, OK)	−1.130**	0.259	−0.324	0.366
Hog buyer requires no antibiotic use	0.195	0.339	−1.252**	0.340
Closed confinement nursery facilities	0.897**	0.275	na	–
Nursery facility age (years)	0.004	0.012	na	–
All-in/all-out nursery management	0.320	0.274	na	–
Weaning age (days)	−0.007	0.010	na	–
Closed confinement finishing facilities	na	–	0.263	0.306
Finishing facility age (years)	na	–	0.004	0.013
All-in/All-out finishing management	na	–	−0.053	0.278
Factor productivity equation				
Constant	1.430**	0.510	1.800**	0.415
Age (years)	0.001	0.005	−0.005	0.004
Education (years)	−0.062**	0.030	−0.028	0.021
Primary occupation is off-farm	−0.322**	0.136	−0.340**	0.107
Years in hog business	−0.002	0.004	0.003	0.004
Planning horizon (years)	0.004	0.008	−0.004	0.005
Size class 2: 500-1,999 hogs	0.530**	0.151	0.587**	0.141
Size class 3: 2,000-4,999 hogs	1.016**	0.215	1.127**	0.224
Size class 4: 5,000 or more hogs	1.276**	0.287	1.263**	0.242
Specialization in hogs (proportion)	−0.012	0.158	−0.046	0.131

(*Continued*)

Table 5. Continued

Variable Description	Nursery Pigs Coefficient	Nursery Pigs Standard Error	Finishing Hogs Coefficient	Finishing Hogs Standard Error
Location in East (NC, VA, PA)	−0.377	0.260	−0.627**	0.176
Location in South (AR, GA, KY, MO)	−0.027	0.141	−0.158	0.119
Location in North (MI, MN, WI, SD)	−0.307**	0.118	−0.347**	0.099
Location in West (CO, KS, NE, OK)	0.194	0.187	−0.038	0.136
Closed confinement nursery facilities	−0.193	0.200	0.032	0.155
Nursery facility age (years)	−0.002	0.005	0.000	0.004
All-in/all-out nursery management	0.001	0.138	0.120	0.113
Nursery disease treatment w/antibiotics	−0.153	0.112	−0.111	0.098
Closed confinement finishing facilities	0.258**	0.132	0.298**	0.151
Finishing facility age (years)	−0.008*	0.004	−0.008	0.005
All-in/All-out finishing management	−0.161	0.114	−0.121	0.104
Finishing disease treatment w/antibiotics	0.117	0.114	0.089	0.109
Terminal crossbreeding	0.417**	0.137	0.439**	0.166
Rotational crossbreeding	0.256**	0.110	0.210*	0.113
Artificial insemination	0.138	0.158	0.231	0.192
Number of rations fed	−0.046*	0.028	−0.058*	0.033
Split-sexed feeding	0.035	0.098	0.047	0.101
STA fed to nursery pigs	0.824**	0.320	−0.007	0.112
STA fed to finishing hogs	0.014	0.091	−0.068	0.173
Sigma	0.624**	0.108	0.545**	0.062
Rho	−0.802**	0.157	0.081	0.149
Log likelihood	−14,702		−17,079	
Number of observations	326		326	

Notes: Dependent variable in the selection equation for nursery pigs is whether the subtherapeutic antibiotics were fed to nursery pigs (0,1). Dependent variable in the selection equation for finishing hogs is whether the subtherapeutic antibiotics were fed to finishing hogs (0,1). Dependent variable in the factor productivity equation is cwt of hog production per dollar to total factor cost (X 10^{-2}). * and ** denote statistical significance at the 10% and 5% levels, respectively; na means not applicable.

characteristics were statistically significant. STA selection for finishing hogs was positively associated with farm specialization, while location in the eastern states, compared to the Midwest, decreased STA selection. Coefficients on the farm size variables were not significant for STA use among finishing hogs, like on the specialized hog finishing operations, indicating no scale bias with STA selection. Also, hog operations with buyers that required hogs not to be fed antibiotics were less likely to feed STA to finishing hogs. None of the production practice variables were statistically significant. A contracting variable was not included because too few contract farrow-to-finish operations were in the sample.

The factor productivity equations estimated for nursery pigs and finishing hogs on the farrow-to-finish operations showed several similarities (table 5). A primary occupation off-farm had a statistically significant and negative impact on factor productivity in both equations, likely due to the reduced time and resource commitment among operators working off-farm. Both models revealed a strong and positive association between size of operation and productivity with coefficients indicating scale-economies in both equations. Farrow-to-finish operations in northern states were less productive than in the Midwest. However, only in the finishing equation was a significant relationship found between lower productivity and location in eastern states, as in the model for the specialized finishing operations. One surprising result was a negative coefficient on the education variable in both models, but this was only significant in the productivity equation for nursery pigs.

Several hog production practices variables were statistically significant in both models, but of particularly interest is the relationship between productivity and the hog breeding program. Variables for terminal and rotational crossbreeding were highly significant and positively related to productivity, indicating that the genetic potential of the hogs has an important role in productivity of the operation. Also significant were hog finishing facility variables that showed finishing hogs in closed confinement to be positively associated with productivity in both equations. Producing hogs in these enclosed facilities likely improves feed and labor efficiency. Oddly, the number of rations fed had a negative relationship with productivity, although at a low level of statistical significance in both models.

With regard to this study, the most important difference between the two factor productivity equations estimated for farrow-to-finish operations is the coefficients on the STA use variable. Feeding STA to nursery pigs had a statistically significant and positive relationship with total factor productivity. It appears that feeding STA is important for maintaining health and enhancing the performance of young pigs when they are most susceptible to disease. Also, the magnitude of the coefficient on the STA variable (0.824) was largest among all hog production practices and second only to the influence of size on productivity, but exhibited a high variance.[4] In contrast, the coefficient on the variable for feeding STA to finishing hogs was not statistically significant.

The estimated correlation of errors of the selection and factor productivity equations, rho, is statistically significant and negative in the farrow-to-finish model for nursery pigs. This result implies a negative selection bias and indicates that the impact on productivity of feeding STA to nursery pigs would have been understated had the selection bias not been taken into account.[5] In contrast, the correlation of errors between the two equations was not significant in either model of STA used for finishing hogs indicating that selection bias was not present in these relationships.

To evaluate the robustness of the results, an alternative model specification was examined. The models were reestimated using antibiotics for growth promotion (AGP) as the dependent variable, as opposed to STA defined as antibiotic used for either growth promotion or disease prevention. Some survey respondents could have confused the difference between disease prevention and disease treatment, or some were using antibiotics for disease prevention and treatment simultaneously because of disease issues on the operation that could have reduced productivity. Or, as research by Miller et al. (July 2003) suggests, the impact on productivity may differ for antibiotics fed for the purpose of growth promotion versus disease prevention.

Table 6. Selection model maximum likelihood estimates: Total factor productivity on U.S. hog operations, antibiotics fed for growth promotion (AGP), 2004

Variable Description	Coefficient	Standard Error
Feeder pig-to-finish operations		
AGP fed to finishing hogs	−0.794	0.653
Farrow-to-finish operations		
AGP fed to nursery pigs	1.015**	0.236
AGP fed to finishing hogs	−0.129	0.156

Notes: Dependent variable in the selection equation for nursery pigs is whether the antibiotics were fed to nursery pigs for growth promotion (0,1). Dependent variable in the selection equation for finishing hogs is whether the antibiotics were fed to finishing hogs for growth promotion (0,1). Dependent variable in the factor productivity equation is cwt of hog production per dollar of total factor cost ($X\,10^{-2}$). * and ** denote statistical significance at the 10% and 5% levels, respectively.

Table 6 shows estimation results of the models with the alternative specification, including only the parameter estimate on the AGP variable for each model.[6] The coefficient on the variable for AGP for nursery pigs was 1.015, up from 0.824 in the STA model, and statistically significant, suggesting that this result was robust to the alternative specification. The coefficient on the AGP variable for feeder pig-to-finish operations remained negative, but increased in value from the STA model and was not statistically significant. Likewise, the AGP coefficient for finishing hogs on the farrow-to-finish operations was not statistically significant as in the STA model.

Conclusions

The analysis of farrow-to-finish operations suggests that feeding STA to nursery pigs significantly improved factor productivity and this result was further supported with an alternative specification. The magnitude of the estimated coefficient suggests that for the average farm, feeding STA increases productivity by more than any other production practice examined in this study. Such a substantial productivity gain may be explained, in part, by which operations benefit most from using STA. The greatest gains in productivity are thought to be on operations that would otherwise be less productive because of less than ideal environmental and management conditions. The negative selection bias found in the nursery pig equation supports this assertion, suggesting that the impact on productivity of feeding STA to nursery pigs would have been understated by not accounting for who chose to use STA. In other words, the operations that fed STA to nursery pigs were otherwise, on average, less productive than other operations due to unmeasured factors. Therefore, feeding STA to nursery pigs may be compensating for differences in management, the quality of production inputs, or other unobserved aspects of the hog operation.

Results from the analysis of feeding STA to nursery pigs suggests that restrictions on feeding antimicrobial drugs during the nursery phase would reduce the average productivity of U.S. hog production as a whole and would impose significant economic costs on hog producers. These costs would likely result from increased pig mortality and reduced animal performance in the short term, and in the long term from necessary adjustments in management and other inputs used on hog operations.

Accounting for exogenous operator and farm characteristics, hog production practices, and sample selection bias, the results of this study showed little relationship between feeding STA and factor productivity for finishing hogs in the United States. The analysis of feeder pig-to-finish producers suggested a negative relationship between STA use and productivity for finishing hogs, but this result was not supported by an alternative specification or by either of the two specifications for finishing hogs on farrow-to-finish operations.

These results suggest that restrictions on feeding antimicrobial drugs during finishing would have little impact on the average productivity of U.S. hog production. These findings do not, however, consider the role that STA may play in the performance of the overall production system. For example, feeding STA likely facilitates the use of other productivity enhancing practices for finishing hogs such as closed confinement facilities and all-in/all-out management. STA use may also reduce the variation in productivity and may be used to reduce production risk and to improve the uniformity of finished hogs. Mean estimates of total factor productivity on feeder pig-to-finish operations were virtually identical for STA users and nonusers, but the variance of these estimates was significantly lower for STA users.[7] Variation in performance is important to hog producers because nonuniformity in hog weights can result in price penalties or reduced contract payments. Further research regarding the impact of STA on the variability of productivity might help to explain why STA are widely fed to finishing hogs.

Results of this study are very similar to those examining the European experience with a ban on STA. Analyses of the European experience suggest little impact for U.S. producers at the finishing stage, but substantial costs incurred from poor animal health and pig mortality at the nursery stage. This study draws a similar conclusion for U.S. hog producers. The lack of a relationship between STA use and productivity for finishing hogs, however, does not correspond with the previous work using NAHMS survey data that suggested a positive association. An important difference between this study and analyses of the NAHMS survey data is how productivity is measured. The previous research implied a relationship between STA use and very narrow measures of productivity associated with a single input, such as feed conversion and average daily gain, while here a broader measure of total factor productivity is used. The previous work also could not account for many of the differences in operator and farm characteristics, and for self-selection bias.

Results of this study are limited, but do shed light on the implications of a potential ban on STA for U.S. hog producers. Most importantly, the economic costs of a ban would likely differ significantly among producers according to the type of ban and how it was administered. For example, a sweeping ban on all STA use would likely have the most severe implications as the sector adjusts to the new regime. A targeted ban, such as on specific antibiotics or particularly on feeding antibiotics to hogs during later phases of production, would likely reduce the economic impact on hog producers. Finally, while this study suggests potential costs of an STA ban for some hog producers, it did not attempt to measure the welfare costs to society of a ban resulting from higher pork prices, nor did it address the potentially large benefits derived from preventing development of antibiotic resistance for the human population or the pork production sector.

Endnotes

[1]In Denmark, the ban took effect first for finishing pigs, poultry, and cattle, which resulted in about a 50% reduction in total antibiotic use. When subsequently, subtherapeutic antibiotic use was banned for weaning pigs, the health consequences were severe enough to force veterinarians to prescribe additional therapeutic antibiotics at levels which then increased total antibiotic use. The increase in usage of therapeutic antibiotics included tetracycline, aminoglycosides, and other antibiotics of direct importance in human medicine (Casewell et al.).

[2]Hundredweight gain is a measure of the value added from the inputs used during the year and equals hundredweight (cwt) of hogs sold or removed under contract, less cwt purchased or placed under contract, plus hundredweight of inventory change during the year. Total costs are the sum of operating and overhead costs, including costs for feed, veterinary and medicine, bedding and litter, marketing, custom operations, fuel and electricity, repairs, paid and unpaid labor, capital, land, general overhead, and taxes and insurance. Pig costs were excluded because they are not an input contributing to weight gain

[3]The density of hog operations and hogs in each county (operations and hogs per square mile), possible indicators of the potential disease pressure in an area, were also considered as explanatory variables in the models. These variables were not statistically significant in any models and were excluded from the final specifications.

[4]A 95 percent confidence interval around the estimated coefficient of 0.824 ranges from 0.197 to 1.451.

[5]Further evidence of a negative selection bias in the farrow-to-finish equation for nursery pigs was found in an ordinary-least-squares regression of the factor productivity equation. The estimated coefficient on the variable for STA use for nursery pigs was much smaller than that estimated with the selection model and not statistically significant.

[6]The coefficients and statistical significance of other variables in the alternative models changed little from that in the original models and thus are not shown in table 6.

[7]The coefficient of variation on the mean of total factor productivity among feeder pig-to-finish operations using STA was 3% compared to 17% for nonusers.

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